Efficient Small Engines for CHP

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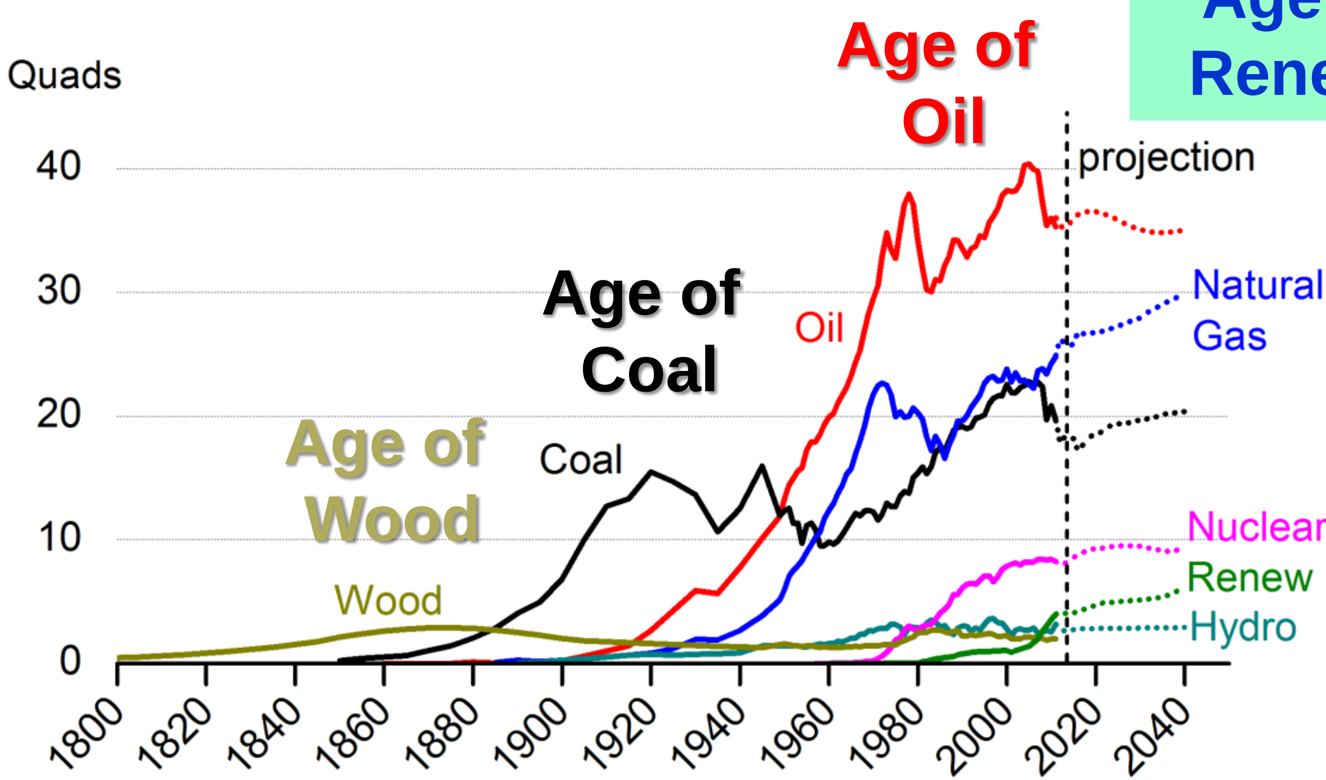
The Business & Environmental Case

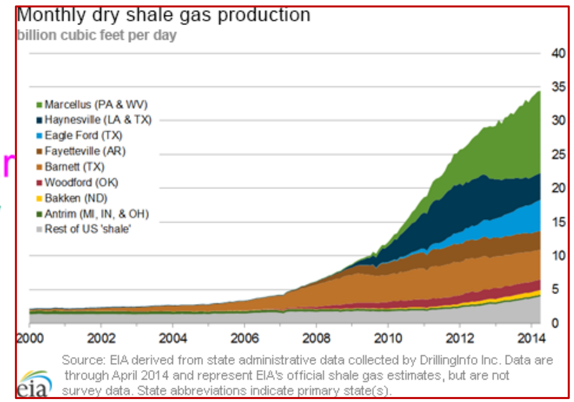
America has abundant natural gas

Efficient use is our responsibility

Total U.S. Energy Consumption

Age of Gas & Renewables ?





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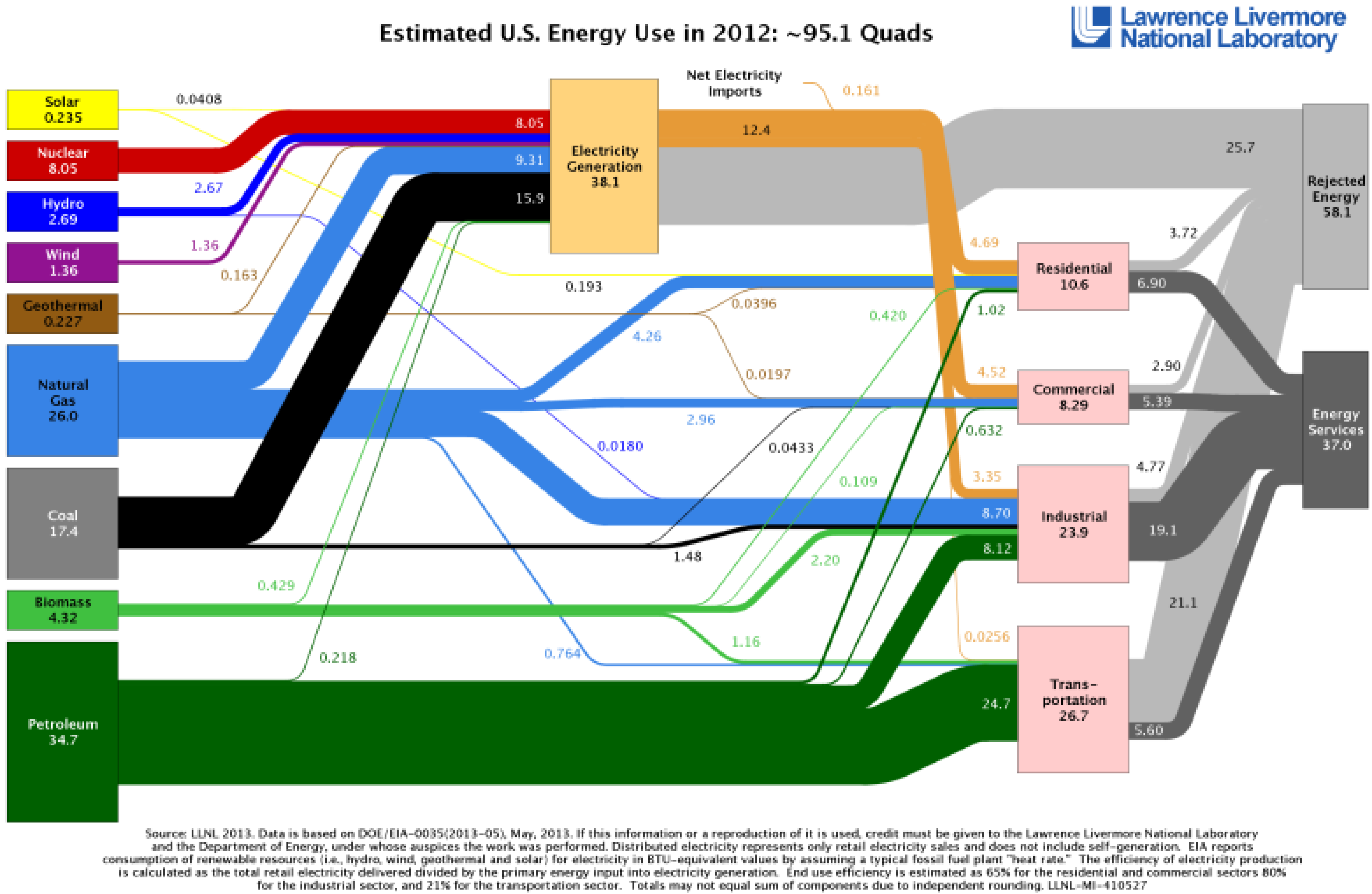
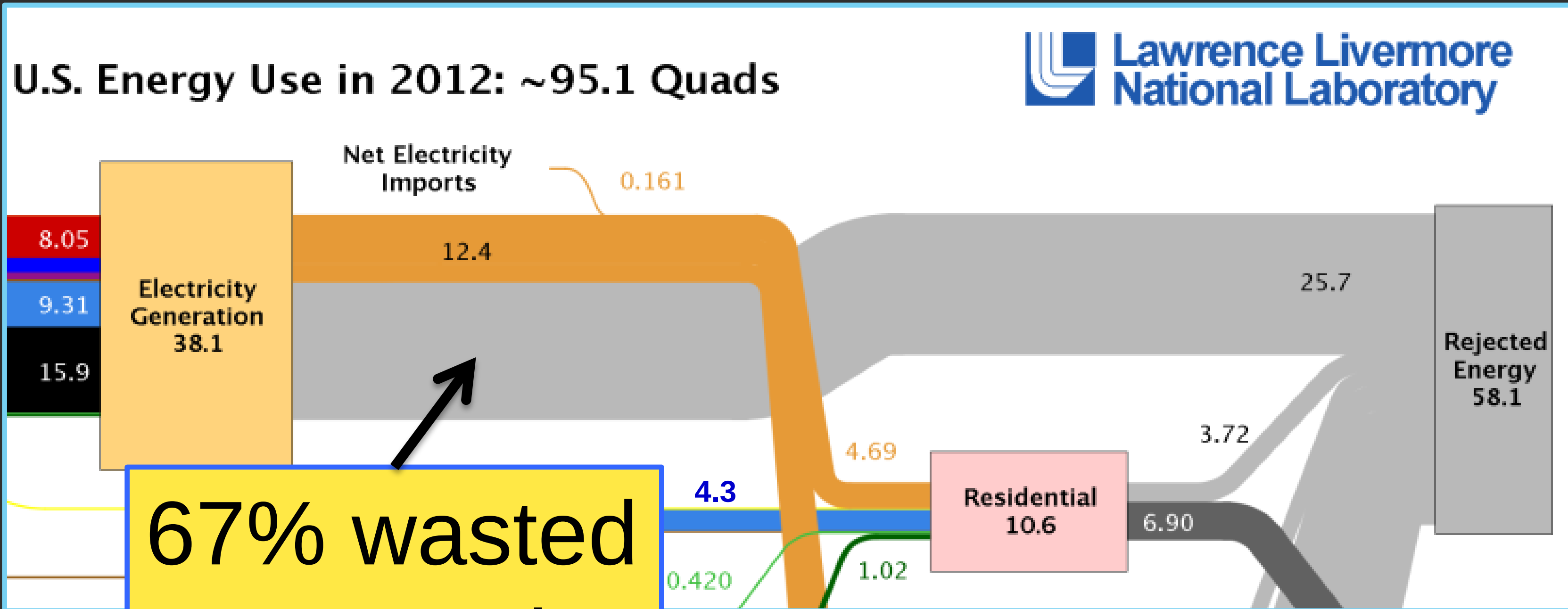
CHANGING WHAT'S POSSIBLE

Source: U.S. Energy Information Administration Annual Energy Review, Tables 1.2, 10.1, and E1.

Centralized Power Waste



Centralized Power Waste



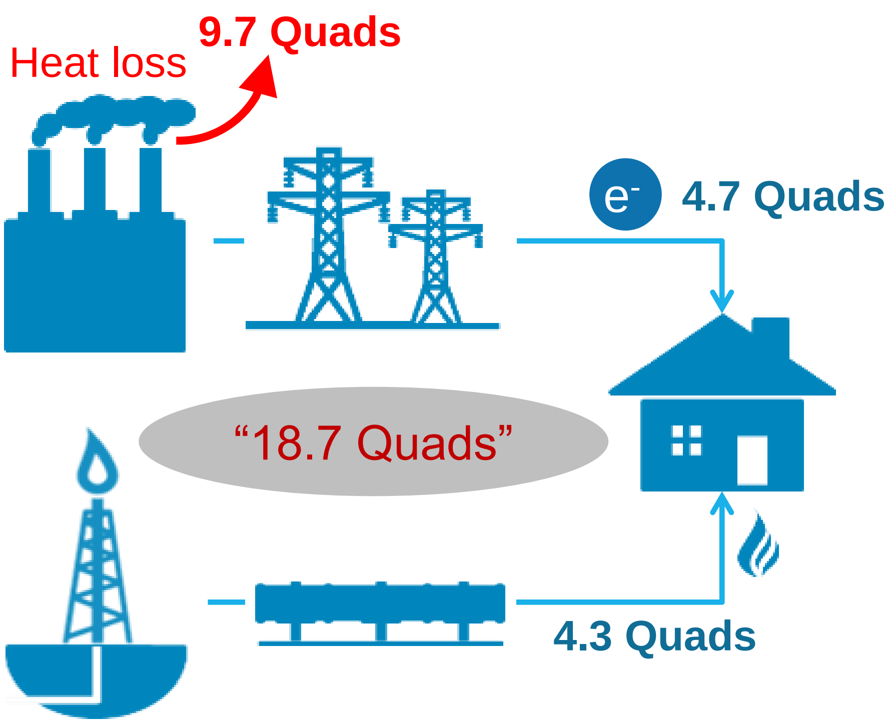
67% wasted
25.7 quads

Combined Heat and Power (CHP)
& Distributed Generation (DG)

Combined Heat and Power (CHP)

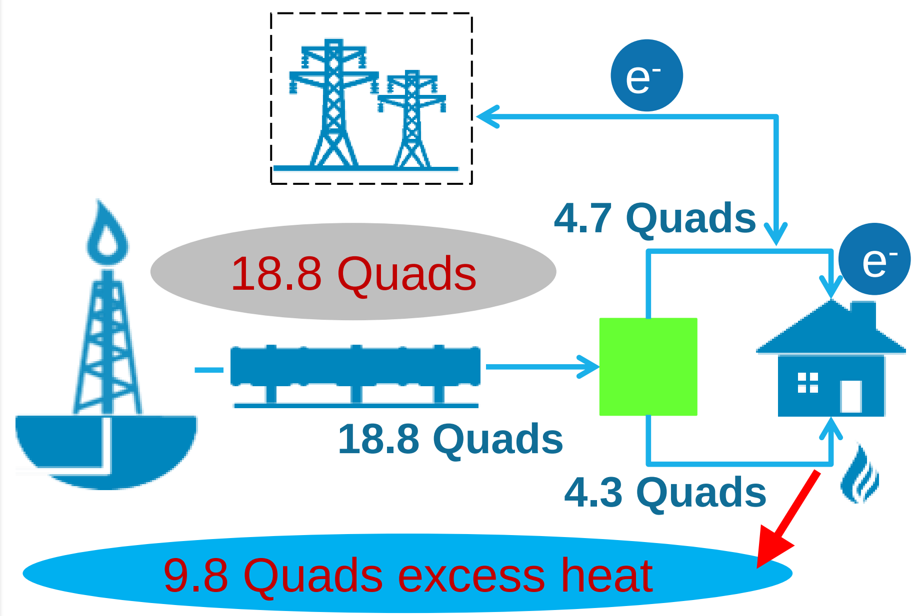
US Residential (Annual total)

Current - Central



CHP

Scenario 1: 25% e^- efficiency

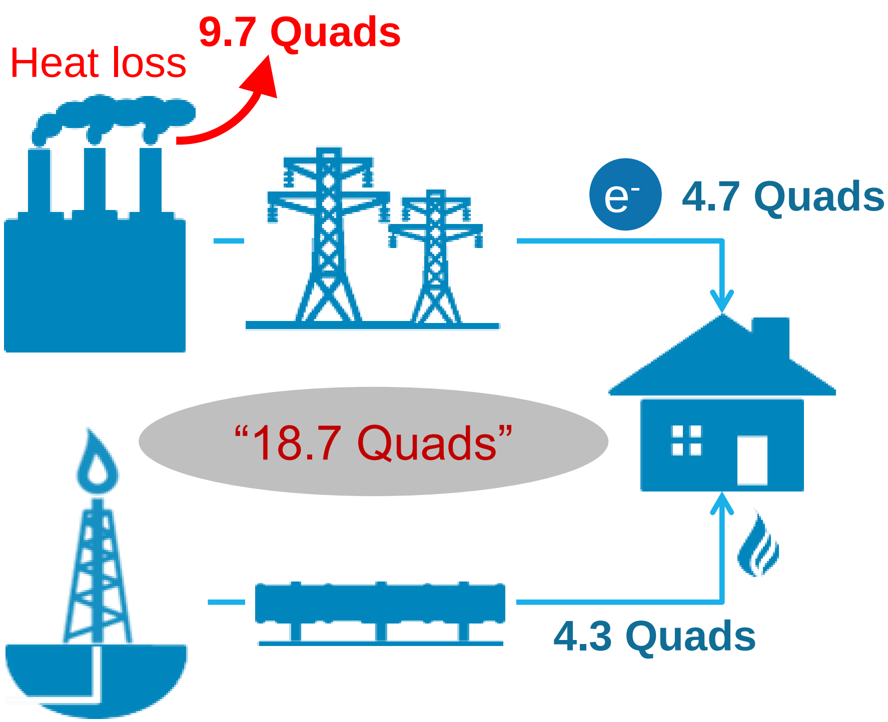


At 25% e^- efficiency, CHP requires of sizable heat storage & utilization systems to be viable or only viable in cold climate states.

Combined Heat and Power (CHP)

US Residential (Annual total)

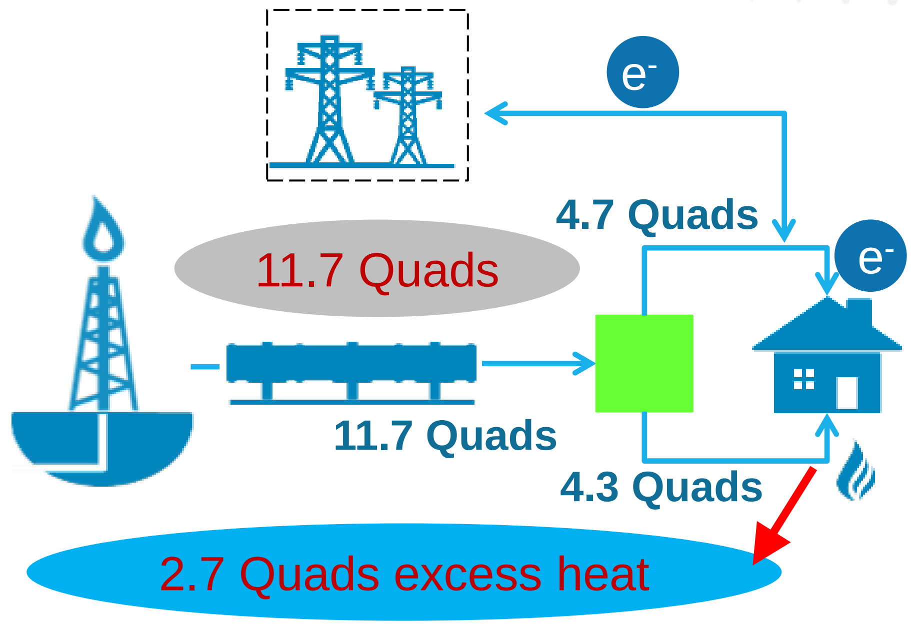
Current - Central



Overall efficiency: 48%

CHP

Scenario 2: 40% e^- efficiency

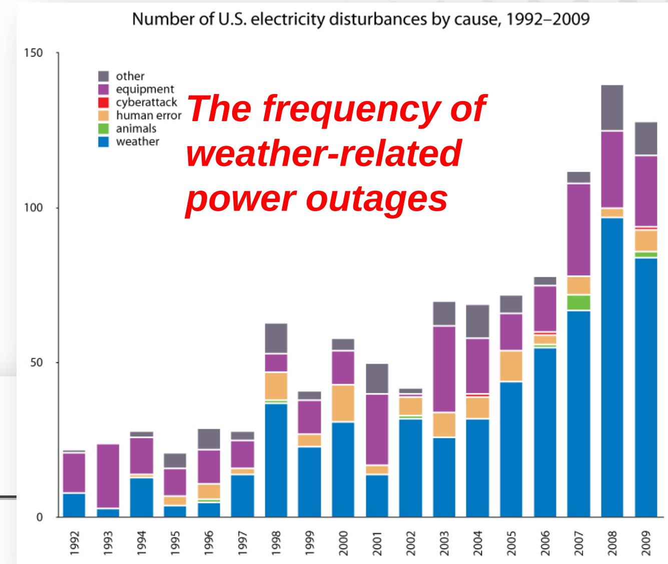


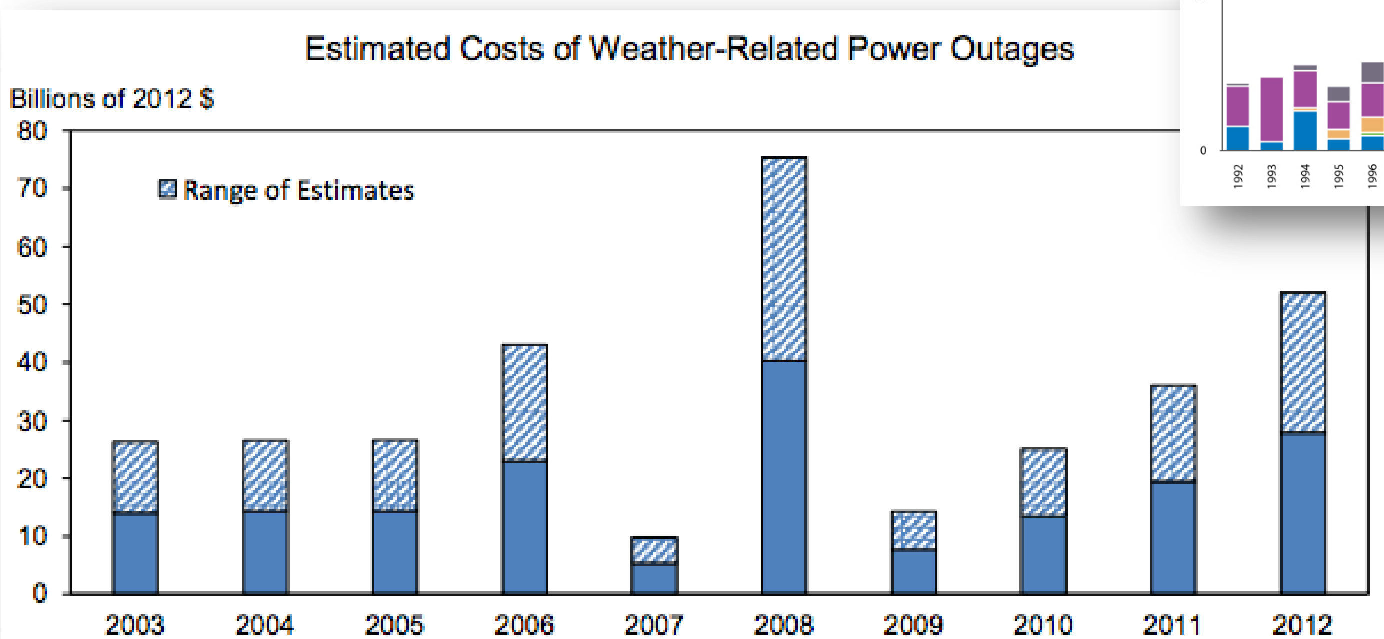
Overall efficiency: 77%

- At 40% e^- efficiency, CHP could save 3 Quads of primary energy for residential
- + 2 Quads for commercial

Additional advantages of CHP / DG

- Power resiliency
- Reduction of electrical grid stress
- CO_2 reduction
- Elimination of loss in transmission & distribution
- Power leveling (e.g., integration with solar)





Source: RMI, White House, LBNL, DOE

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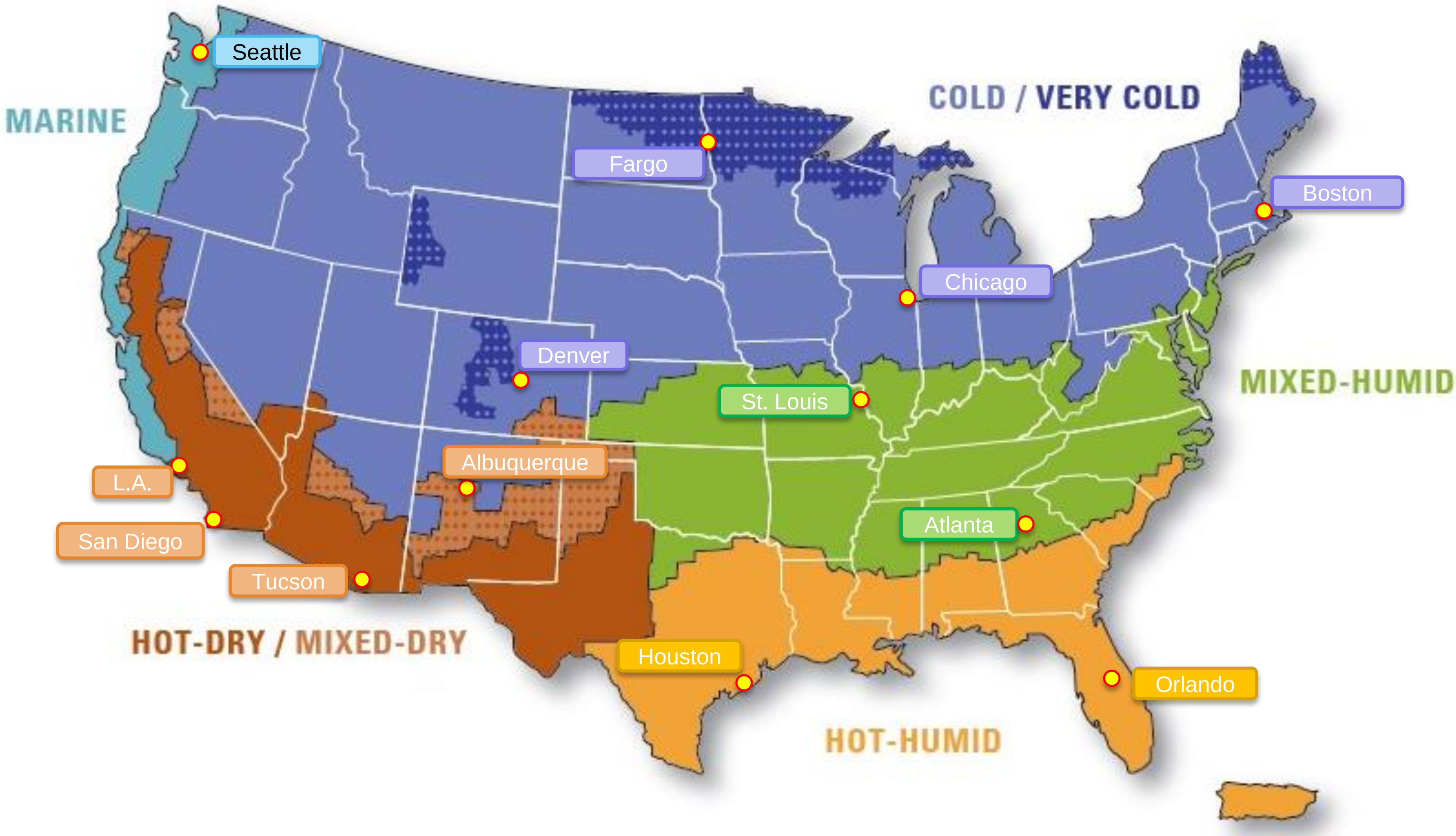
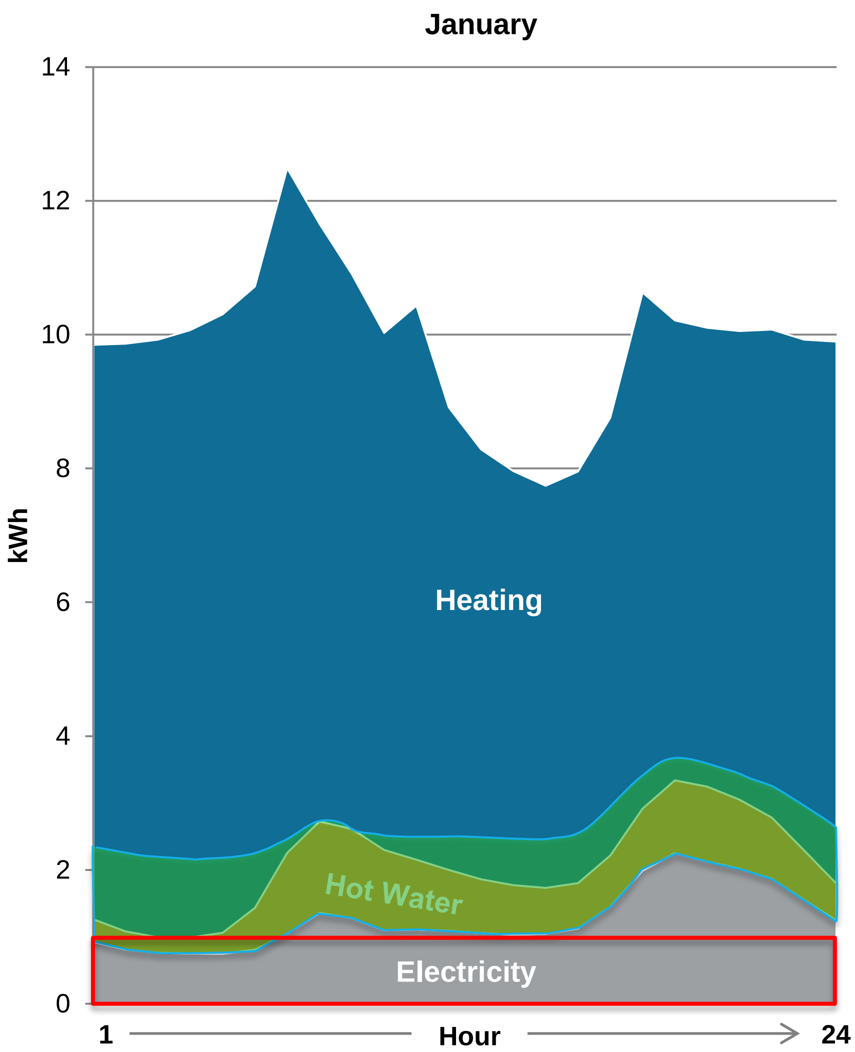
What's the right size for home CHP ?

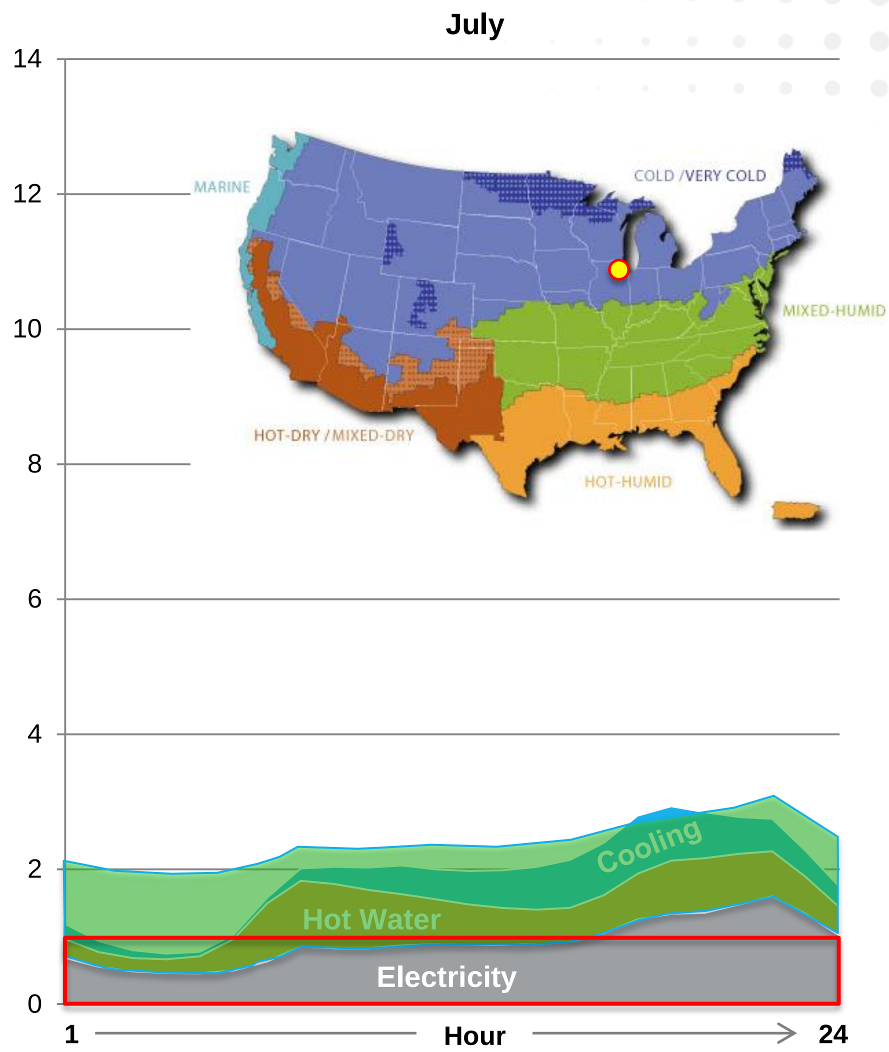
US climate zones



Source: http://www.eia.gov/consumption/residential/maps.cfm

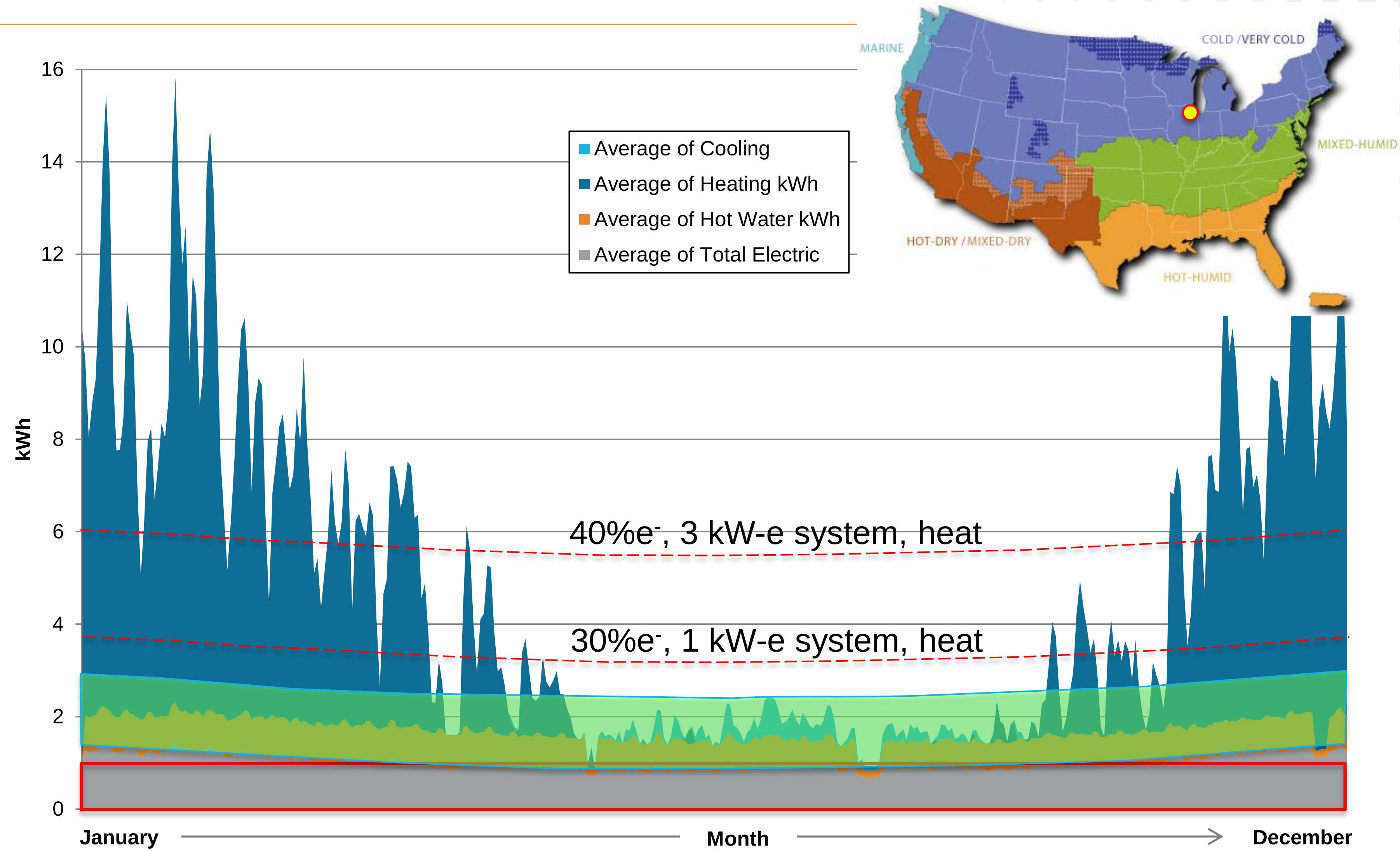
Hourly residential load profile: Chicago





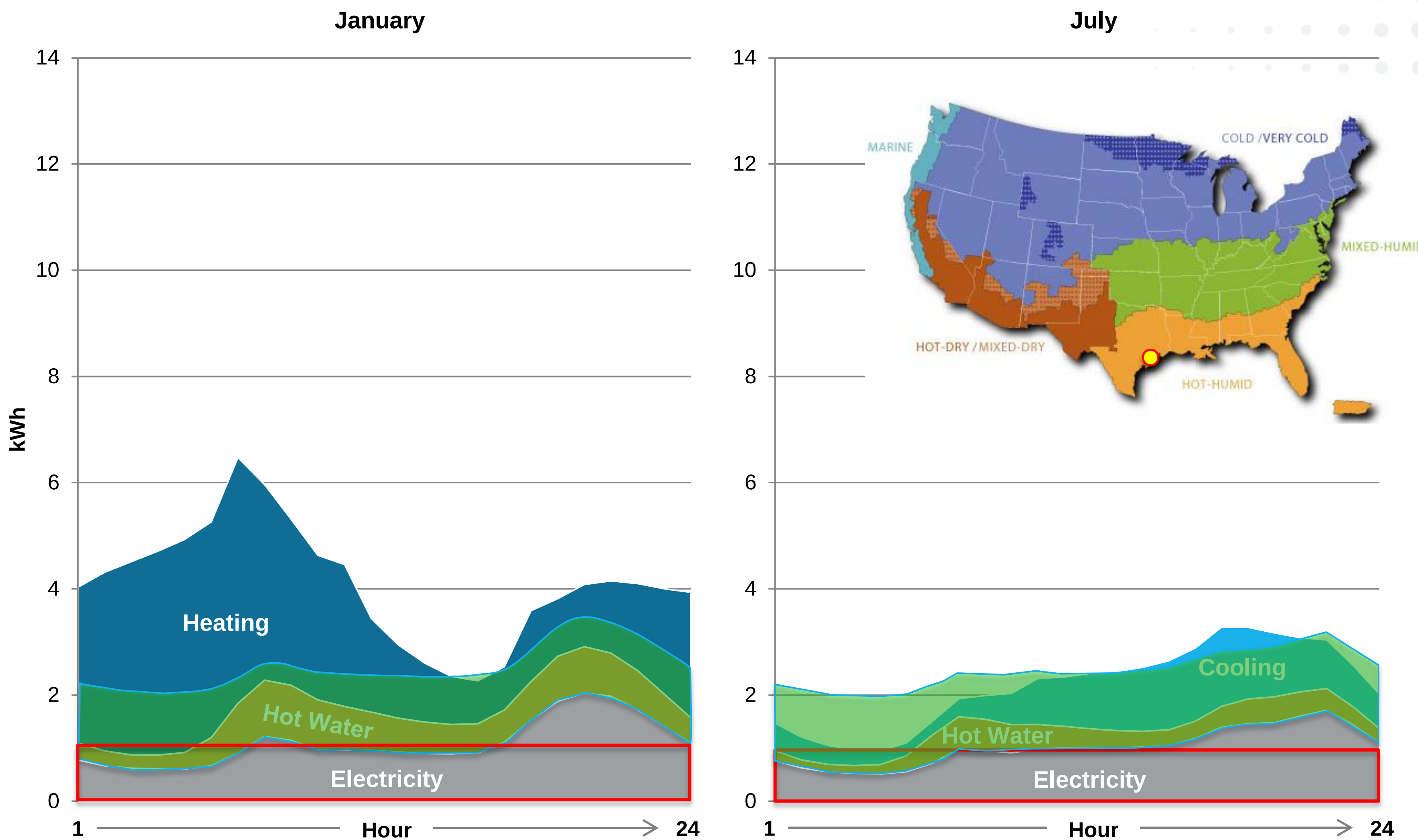
CHANGING WHAT'S POSSIBLE

Annual residential load profile: Chicago



Source: NREL BEopt

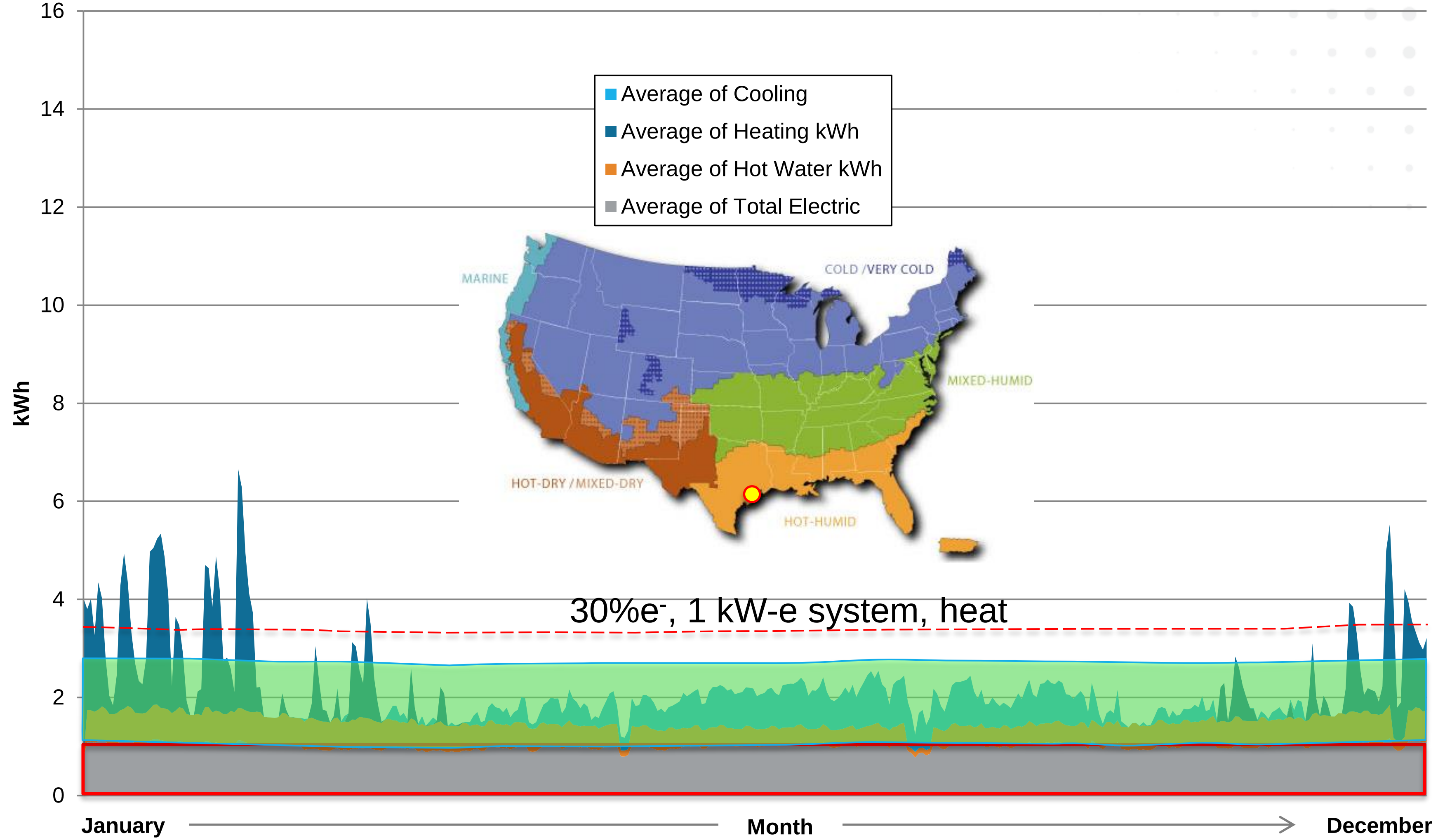
Hourly residential load profile: Houston



Source: NREL BEopt

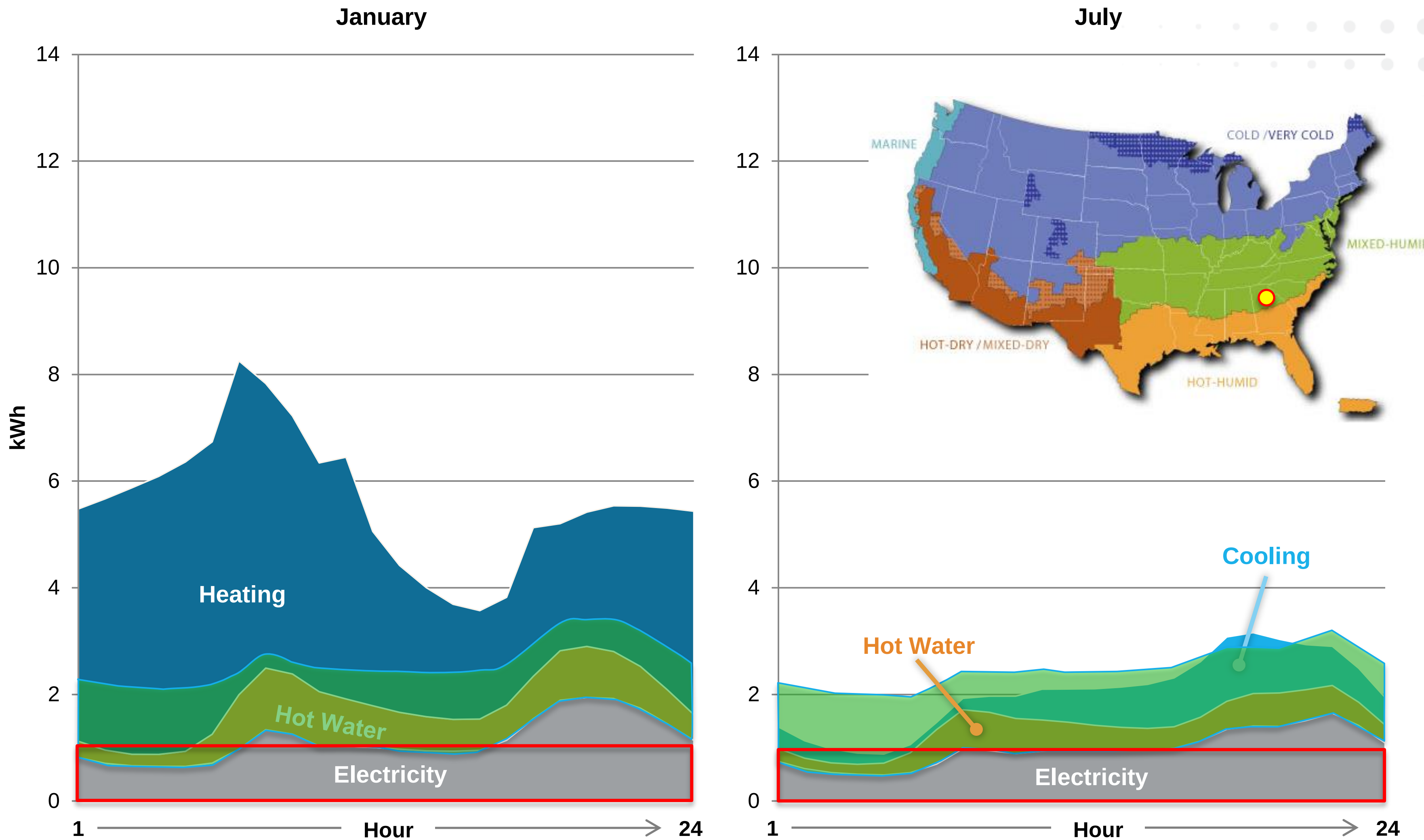
CHANGING WHAT'S POSSIBLE

Annual residential load profile: Houston



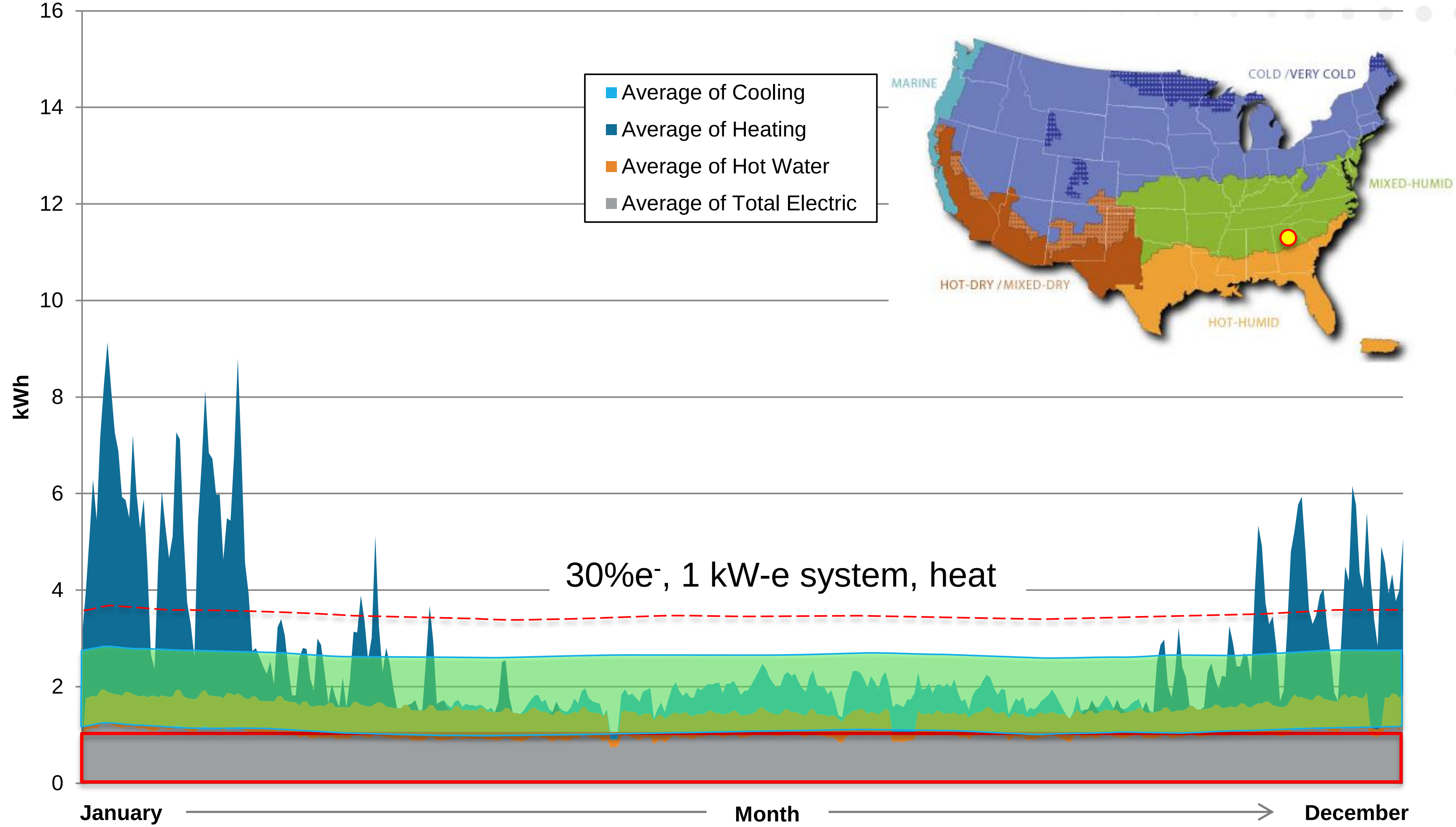
Source: NREL BEopt

Hourly residential load profile: Atlanta



Source: NREL BEopt

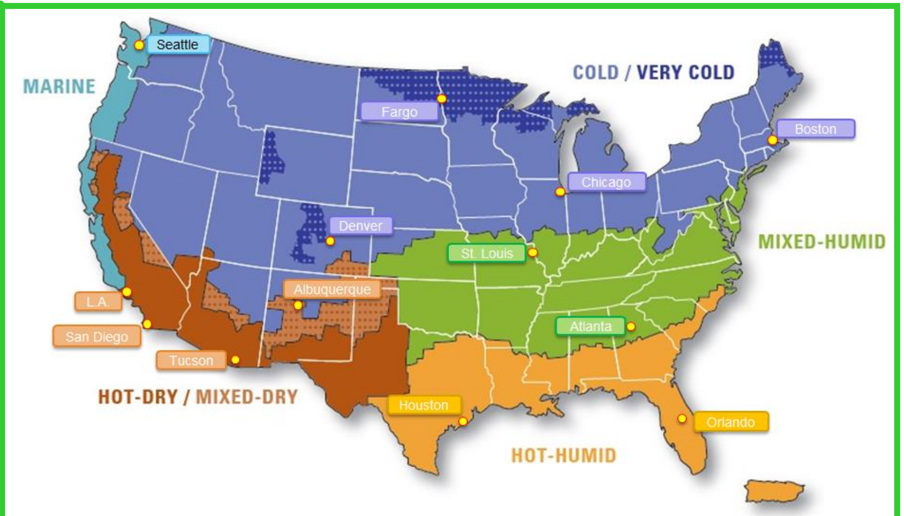
Annual residential load profile: Atlanta

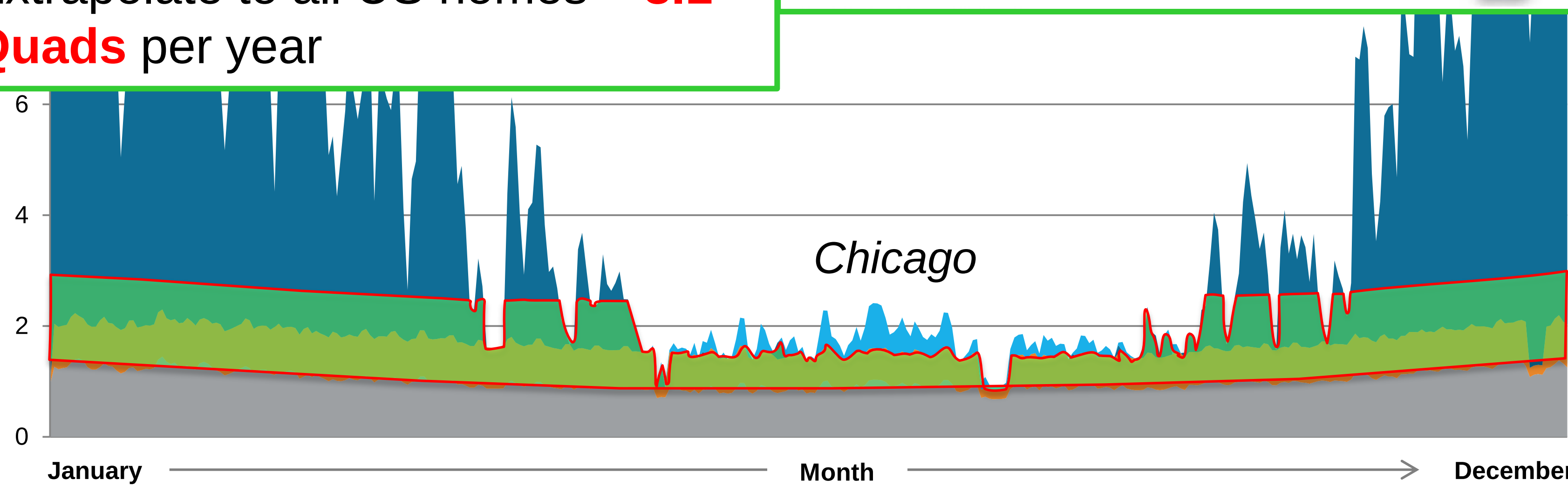


Source: NREL BEopt

Energy saving calculations

- Integrate usable heat hourly to a yr
- Average across each climate zone
- Multiply the number of homes with NG at each zone
- Obtain total energy saving by usable heat = **1.9 Quads** per year for 69M US homes with NG
- Extrapolate to all US homes = **3.1 Quads** per year





Source: NREL BEopt

Techno-Economic Analysis

Thermodynamics predicts what’s possible.

Economics dictates whether it will occur.

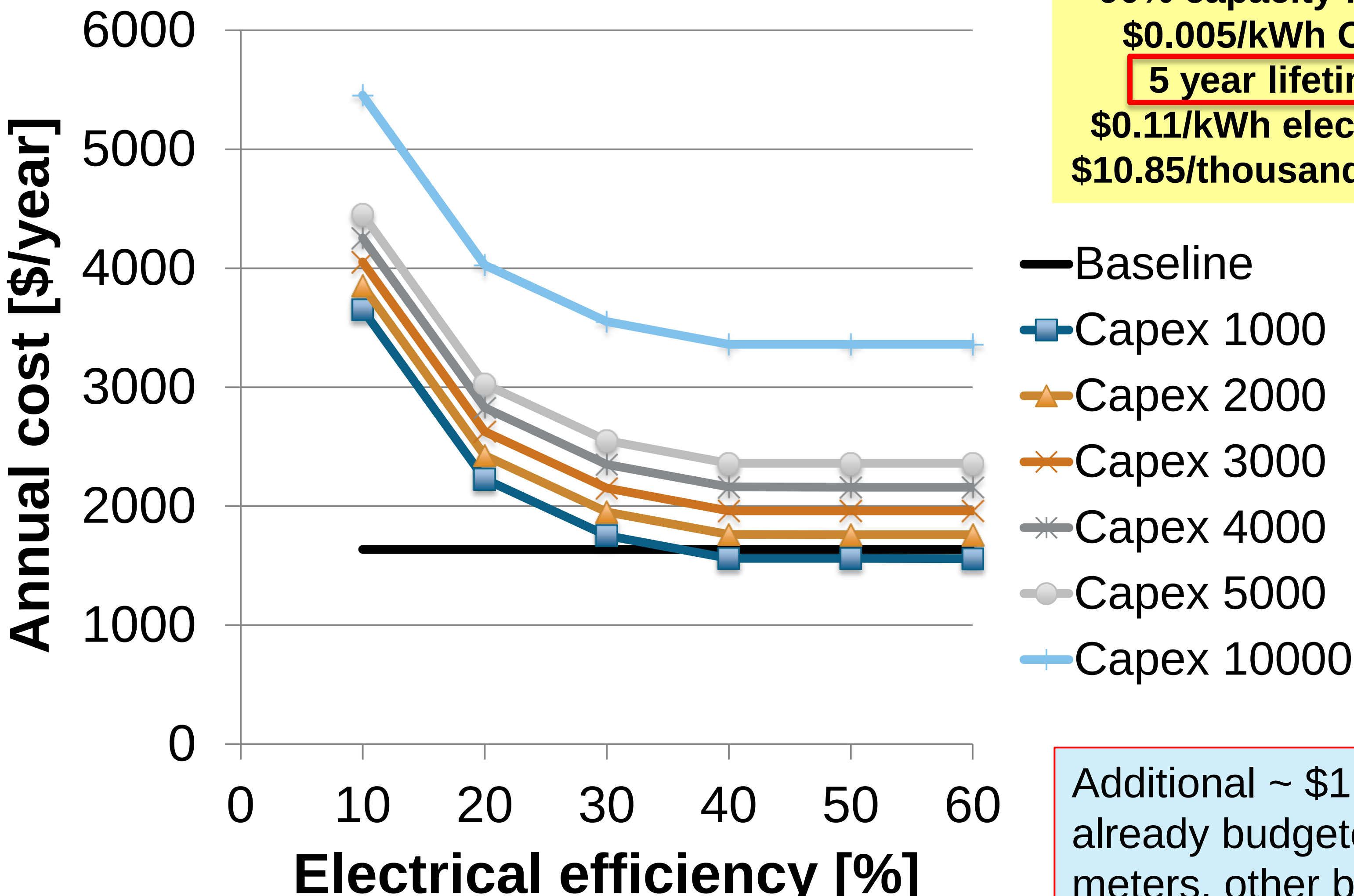
Techno-economic analysis

- Most customers want to remain on the grid
- System size to 1 kW (minimum electricity sell to utilities)
- 90% capacity factor
- System (CAPEX) and installation cost
- Durability/lifetime of the system
- Different modes of operations not considered

Widespread adoption requires little or no government incentives

Techno-economic analysis

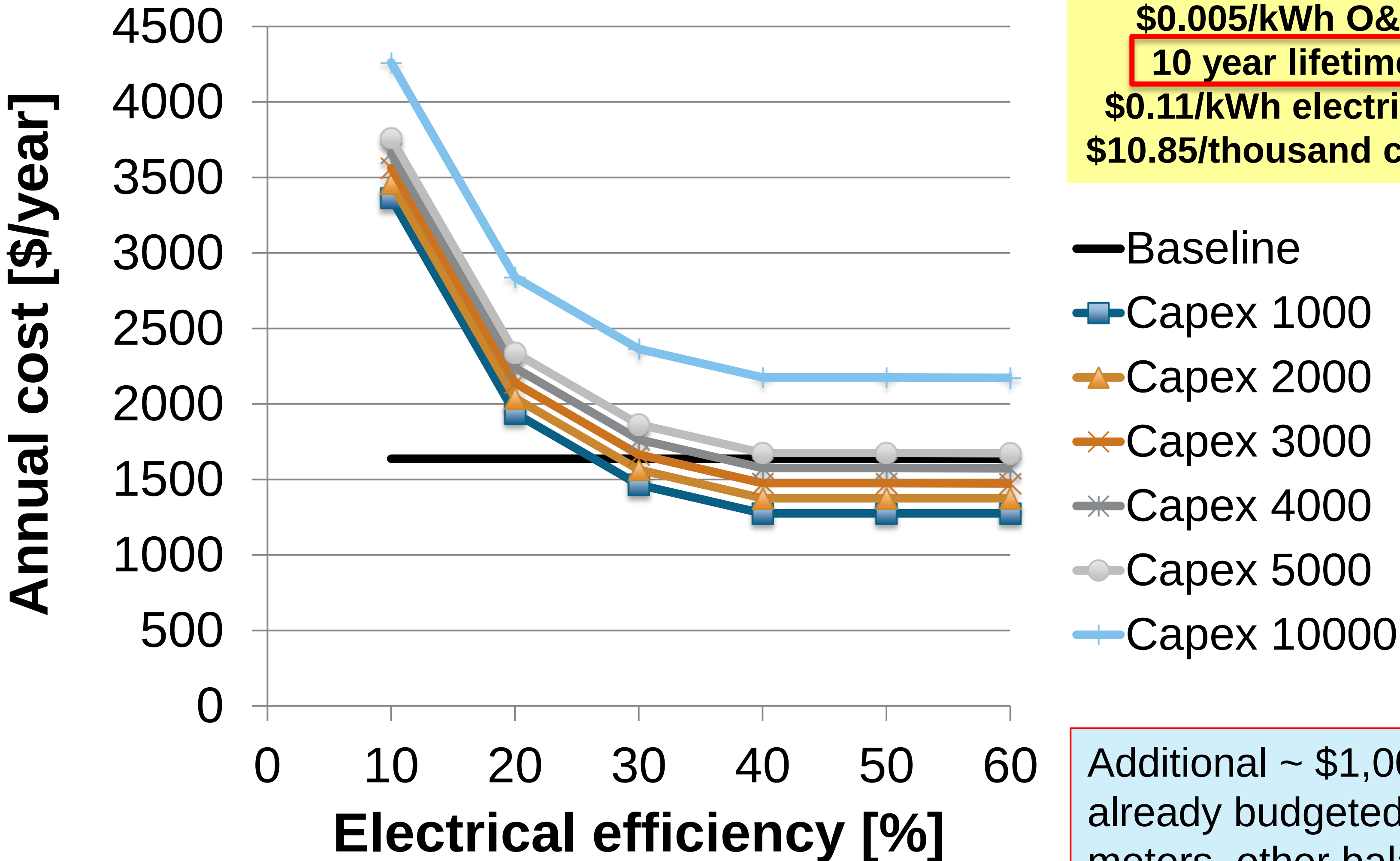
Assumptions
1 kW electrical load
1.5 kW heat load
90% capacity factor
$0.005/kWh O&M
5 year lifetime
$0.11/kWh electricity
$10.85/thousand cf NG



Additional ~ $1,000 already budgeted for meters, other balance of plant & installation

$0.036/kwh-NG

Techno-economic analysis



Assumptions

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$0.005/kWh O&M
10 year lifetime
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Techno-economic analysis

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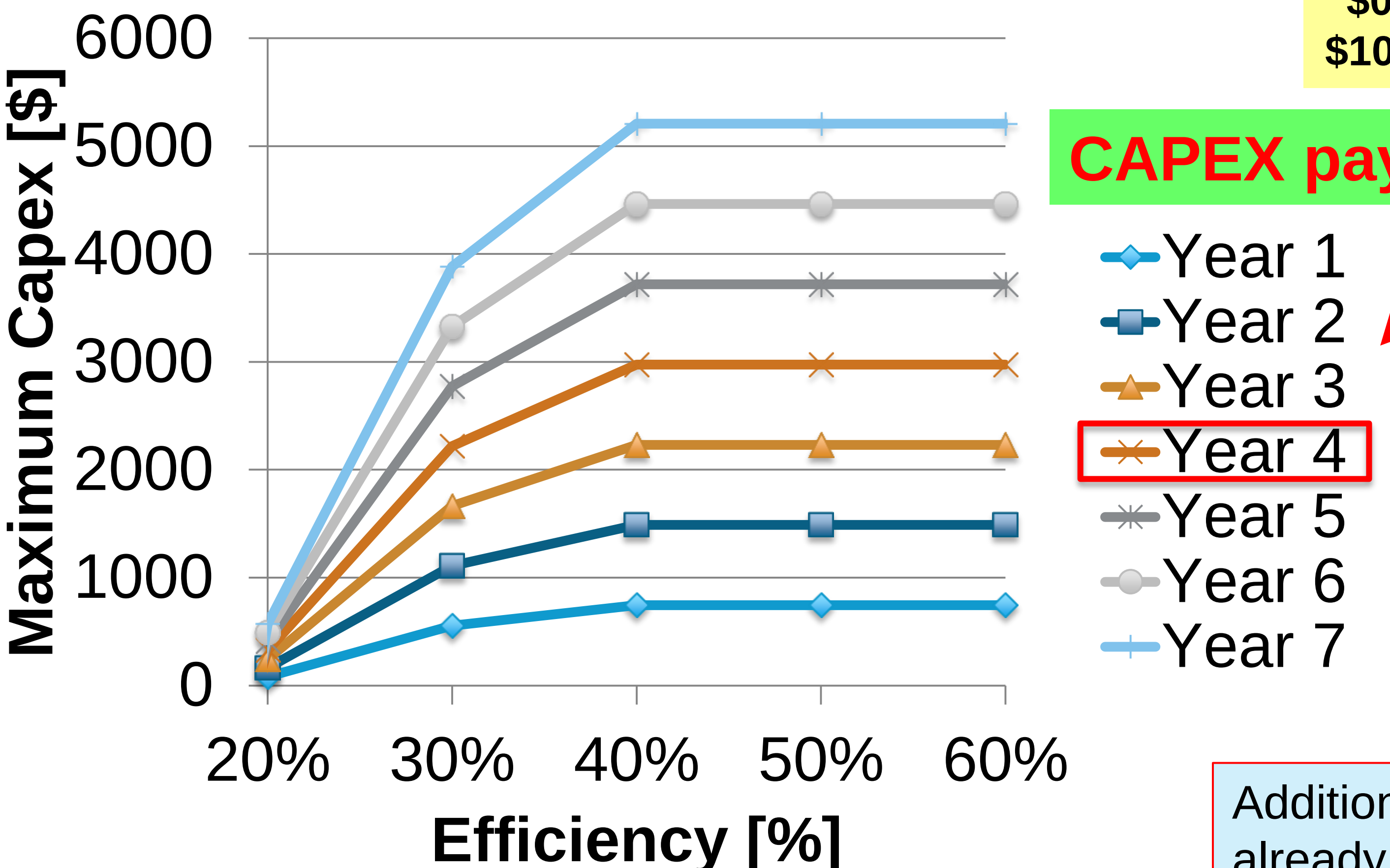

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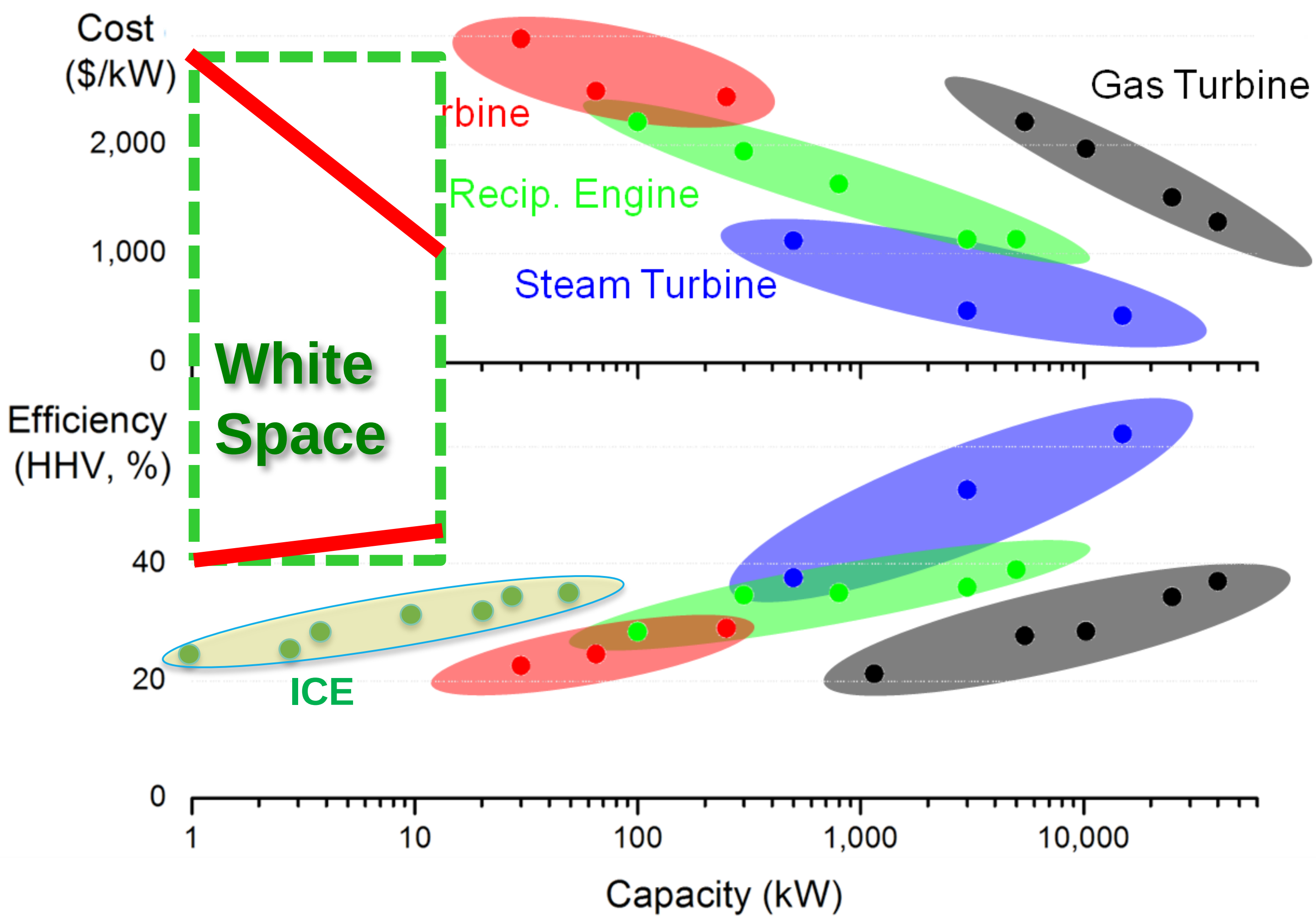
CHANGING WHAT'S POSSIBLE

Technology Pathway & White Space

~ 40% electrical efficiency
~ 10 year durability/life
< $3,000 for a 1 kW-e system

White Space – Technology needs



Durability
Emission
Noise

ICE data from W. Liss, ARPA-E Small Engine Workshop presentation

Source: Adapted from Catalog of CHP Technologies, U.S. Environmental Protection Agency Combined Heat and Power Partnership (2008).

40% e^- efficiency 1 kW-e system feasibility

Mechanical / Combustion ⟷ Solid State

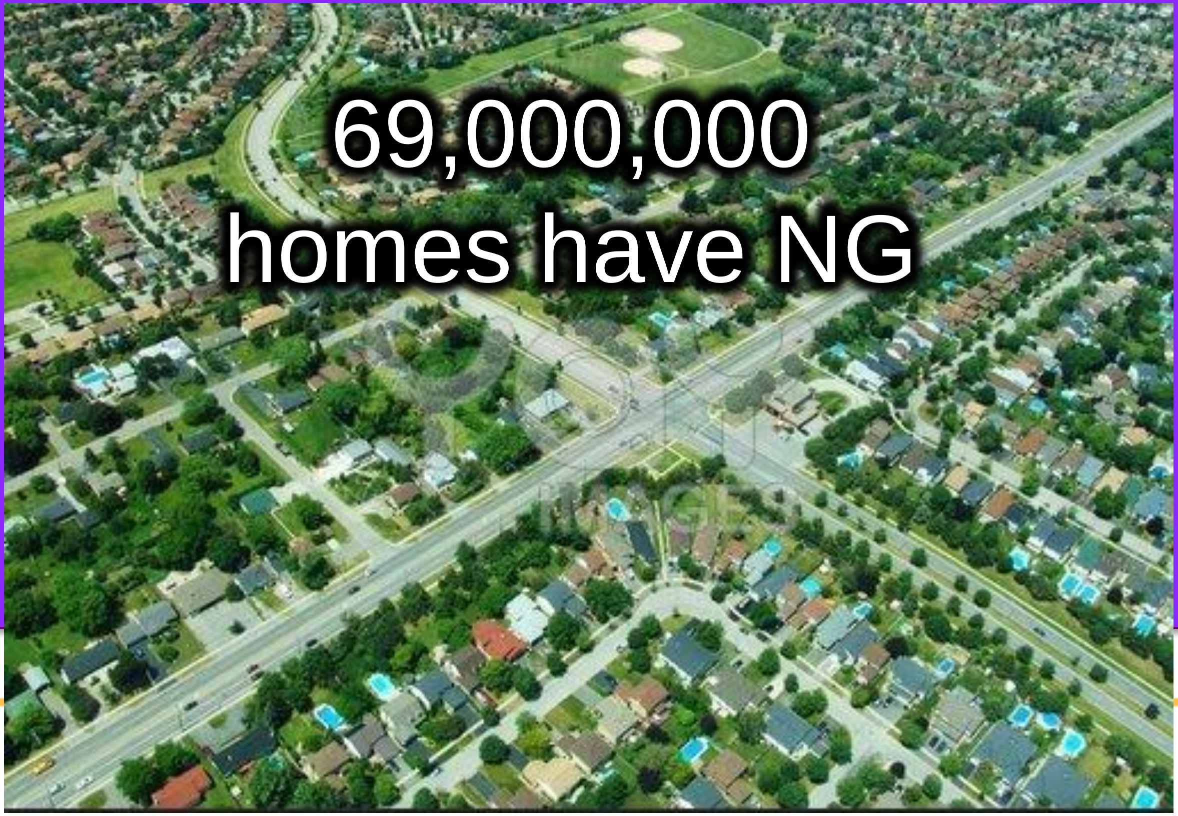
- Stirling engine
- ICE
- Microturbine
- Thermoacoustics
- ……

- Thermoeletrics
- Ion expansion (Na, O)
- Thermionic emission
- Electrocalorics
- Thermophotovoltaics
- ……

Coupling with Materials and Manufacturing Innovations …

Cost, Durability, Emission, Noise

Deployment Challenges & Opportunities



Deployment Challenges

- Utility acceptance
- Integration with the forced air heating/cooling
- Heat to cooling for southern states
- Emissions regulations
- Consumer acceptance and benefits
- Initial investment

Changing Regulatory Environment

- Addressing Interconnection: IEEE DG Standards Document 1547
  - Updated 8 times since creation, with specific changes that reflect rapid changes in DG interest[1]
  - Power quality, interconnection standards, voltage regulation, islanding, active management

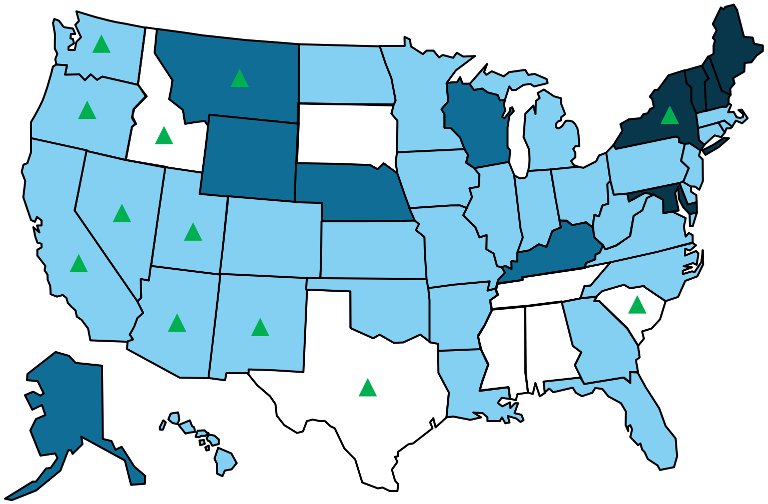
- Business Model Disruptions:
  - Players support change: NRG supports customer independence, counter to NRG direction[2]
  - Utility Death Spiral Hype:
    - Edison Electric Institute alarmist report[3]
    - Changes in policy that allow utilities to own DG and offset infrastructure support loss/death spiral

- FERC Order #755 & #784 Pay-for-Performance:
  - Reduces technology payment "discrimination"—requires consideration of speed and accuracy[4]

1. MITEI, "The Impact of DG and EV", Chap. 5, mitei.mit.edu
2. http://blogs.wsj.com/corporate-intelligence/2013/03/22/utility-boss-faces-mortal-threat-from-solar/?KEYWORDS=crane+mortal
3. http://www.eei.org/ourissues/finance/Documents/disruptivechallenges.pdf
4. http://www.ferc.gov/whats-new/comm-meet/2011/102011/E-28.pdf

Net metering and interconnection standards

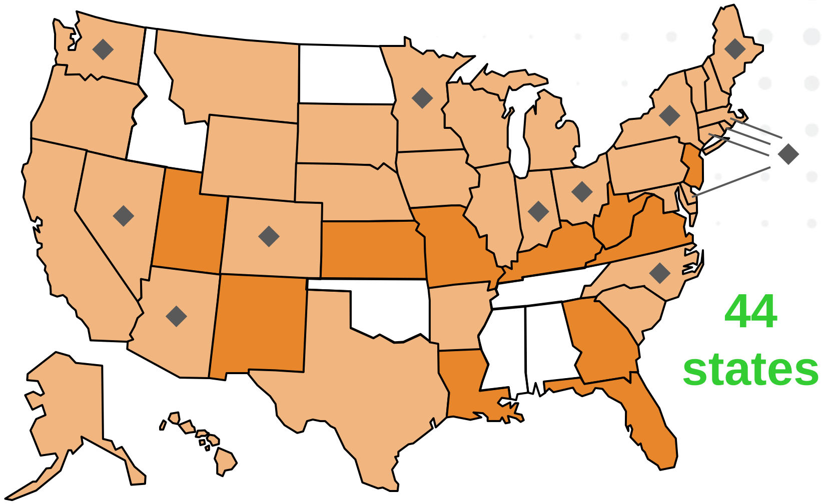
States with net metering rules



- **Only** systems smaller than 50 kW eligible
- Specific rules for micro-CHP
- ▲ States with utility-level net metering rules

43 states

States with interconnection standards



44 states

- Renewable generation or fuel cell systems only
- ◆ Mandatory state EERS or RPS* includes CHP/waste-heat

Several states have specific net metering policies for micro-CHP	
New York	10 kW system capacity limit for micro-CHP; net excess generation is credited at the utility's avoided cost rate
Vermont	20 kW system capacity limit for micro-CHP
Maryland	30 kW system capacity limit for micro-CHP
New Hampshire	CHP systems <30 kW must have a system efficiency of at least 80% to be eligible
Maine	CHP systems <30 kW must have a combined electrical and thermal efficiency of at least 80% to be eligible

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* EERS = Energy efficiency resource standard
RPS = Renewable portfolio standard

Source: DSIRE, Freeing the Grid, EPA, EPA

Spillovers & Opportunities

Spillovers and Other Opportunities

- Commercial & industrial CHP
- Military power
- Backup power systems
- Concentrated solar power (CSP)
- Generator for hybrid light-duty vehicles

Wikipedia

Easier to scale up than scale down

Workshop Objectives

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- Identify the white space & metrics
- Bring researchers on mechanical engines together with those on solid-state devices
- Stimulate innovations with mini-presentations
- Identify potential technology pathways
- Foster teaming
- Identify barriers to widespread deployment

Efficiency, Cost, Durability, Emission, Noise

Workshop Objectives

Bottom-line:

What can we do to enable widespread adoption of home/residential CHP ?

Efficiency, Cost, Durability, Emission, Noise

Welcome and Thank You